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WALKING UNDER ZERO-GRAVITY CONDITIONS USING VELCRO MATERIAL

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INTRODUCTION

In any walking movement, the person performing the movement must have contact with the surface upon which he is walking. The normal 1-G walking gait is a push-pull operation. The push is upward and forward through the longitudinal axis of the body. The swinging leg moves forward and decelerates. There is a transfer of energy (pull) from the decelerating (swinging) leg to the remainder of the body, thus promoting a smooth forward motion of the body. The heel of the swinging leg strikes the ground, then the toe is eased down placing the foot flat on the ground. The next cycle begins with a push off by the other leg.[1]

A weightless man on a normal surface can never complete the full walking cycle without external assistance. The initial push upward and forward imparts an acceleration away from the walking surface. This acceleration is more than overcome at the surface of the earth, but in space it is not even decreased. The subject generates a net acceleration at an angle with the surface great enough to free him from contact with the surface, unless some restricting device is used.

The initial study reported here had as its purpose the evaluation of man's ability to walk under conditions of weightlessness while using Velcro material[2] as a means of maintaining surface contact. Velcro consists of two mating pieces of fabric: a hook portion containing many small nylon hooks, and its mating material, pile, consisting of many small nylon eyes or loops. When the two materials are pressed together, the hooks engage in the eyes and the two portions adhere. Under laboratory conditions, a perpendicular force of about 9 pounds per square inch is required to separate the materials however they can be <u>peeled</u> apart with about 0.9 pounds per inch of width. The high force needed to pull the materials straight apart compared to the low force needed to <u>peel</u> the same amount of material is the quality that makes Velcro particularly interesting as an external aid to permit walking while weightless.

APPARATUS AND GENERAL PROCEDURE

The study was conducted using a C-131B cargo-type airplane, modified by padding the floor, walls, and all protruding pieces of equipment to prevent collision injuries to free-floating subjects. The aircraft flew repeated Keplerian trajectories producing approximately 14 seconds of continuous weightlessness during each run.

[1]Personal communication from Dr. H. J. Ralston, found in reference 7, Page 53.

[2]Manufactured by the Velcro Corp., 681 Fifth Ave., New York 22, New York.

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To provide an adhesive walkway the hook portion of the Velcro material was fastened to the ceiling of the airplane to form two tracks, each 6 inches wide and 13 feet long, located 12 inches apart from center to center. In the first of the experimental trials, some subjects were unable to keep their feet on these 6-inch treads. Consequently, the divided walkway was replaced by a solid walkway 26 inches wide and 13 feet long. The pile portion of the Velcro material was affixed to the soles of two pair of gym shoes (one pair size 8, the second pair size 10½) from which the tread had been ground. In the course of the experimental trials, various materials were inserted between the sole of the shoe and the Velcro material in an effort to increase walking efficiency.

When the airplane was about to enter a zero-gravity maneuver, the subject was asked to lie flat on his back, parallel to the overhead walkway, with his head pointed in the direction that he would be walking. At the beginning of the zero-gravity portion of the maneuver, the subject would raise his legs toward the walkway and push against the floor with his hands, thus forcing his feet up to the walkway and engaging the Velcro on his shoes with that on the walkway. Once the feet were attached to the walkway, the subject would hold himself in a vertical position by putting his hands on the floor of the aircraft until the aircraft stabilized into a smooth trajectory. When the trajectory was smooth and the subject was ready to walk forward, he would remove his hands from the floor and attempt to walk forward until the aircraft maneuver ended. The subject then let himself settle to the floor in readiness for the pullout.

Seven subjects were selected on the basis of availability. No consideration was given as to whether or not they had had prior zero-G experience. None had walked during zero-G using Velcro material prior to this experiment.

A handheld, 16mm., BlA-type Bell & Howell and Bolex movie camera operating at 32 frames per second was used to photograph all walking trials.

EXPERIMENTS AND RESULTS

The first aid to weightless walking investigated was a pair of tennis shoes with the Velcro material cemented directly to the sole of the shoe without padding under the toe or arch. Early observations indicated that the holding power of this configuration was not great enough due to the limited area of surface contact. To remedy this, the area of shoe-to-walkway contact was increased by filling in the instep and the area beneath the upturned toe to make a completely flat sole. The first insert material used was natural rubber latex, type 60965 S/N 9320NL (as used in the new light weight oxygen mask*). Because this material would not retain its shape under the stresses of walking, it was not considered to be entirely satisfactory even though it was a great improvement over the original configuration. With this second configuration the subject could successfully overcome minor accelerations produced both by the aircraft motion and himself.

In an effort to find a more suitable base for the Velcro material, three different insert materials were tried. The first of these consisted of a type AH Ensolite (the material used on boxing ring floors to absorb the shock of falling). This material proved to be unsatisfactory because of the quality in the material that prevented it from returning to normal immediately. The second material, a very soft sponge rubber insert, proved to be unsatisfactory. Although the material returned to its original shape when released, the extreme softness of the material appeared to limit the adhesive effectiveness of the configuration. To alleviate this problem a resilient insert material of type M Ensolite was tried. This appeared to be the best configuration.

When movies of all the trials were examined, particular patterns of walking were observed. Some of these patterns resulted in virtually total failure in attaining a successful walking gait, while during those trials in which some degree of success was noticed, there was evidence of characteristic movements or body attitudes.

The posture that seemed to be present whenever a successful walking gait was attained can be described as a crouched position, with the knees bent and the upper portion of the body bent forward (see figure 1). When the subject's knees were not bent, the motion of his legs during the first part of a step pushed his body away from the walkway, and he found it impossible to reach the walkway on succeeding steps. If the upper portion of his body was not bent forward, even though his knees were bent, leg accelerations pushed him farther away from the walkway with each succeeding step, until he could not reach the walkway. Bending the upper portion of the body forward lowers the center of mass, bringing it closer to the walkway, thus giving the subject greater control over movements in all directions. As he pulls his foot off the floor and bends his leg, the greater mass of the body above the waist appears to be used to counteract the forces produced by his legs. In spite of the gyrations produced by various segments of the body, the center of mass of the body as a whole must follow a path parallel to the surface being walked upon.

Subject-induced lateral motion appears to affect the walking gait. If the importance of these lateral motions is substantiated in future investigations, some thought may be given to fabricating and installing a walkway on which the surface for each foot is perpendicular to the axis of the leg. This would result in a ceiling walkway in a shallow inverted-V form.

To date, three methods of returning the foot to the walking surface have been observed: (1) putting the foot down with a slight aft motion, (2) putting the foot straight down, and (3) putting the foot down with a slight forward motion. The data obtained in the course of this preliminary study did not clearly indicate the most effective method.

Fig 1. <u>Subject Walking Under Zero Gravity Conditions While Using Velcro Material</u>. The body posture shown (knees bent, upper torso inclined forward) produced the most successful walking gait observed under the conditions of this study.

CONCLUSIONS

The following conclusions can be derived from this initial study.

1. Velcro material applied to a maximum area, flexible shoe with a resilient, flat sole appears to hold some promise as an aid to "weightless walking."

2. Under the conditions of this study, the body posture that permitted the most successful walking gait was a crouched position, knees bent and the upper portion of the body bent forward. This posture apparently best enables the center of mass of the body to maintain a straight line path parallel to the walking surface.

3. Subject-induced motions appear to play a definite part in attaining a good walking gait. Swinging the arms, the velocity with which the legs are raised off the floor, and the technique that is used in separating the Velcro material on the shoes from that on the walkway all play a part in the success or failure of maintaining useful contact with the walking surface.

FUTURE INVESTIGATIONS

It would be desirable to record quantitative measures of subject performance. Two measurement systems are being considered for inflight research. In one system a recorder and accelerometer system may be used to record the horizontal, vertical, and longitudinal aircraft accelerations. Concurrently, inputs from the subject should be used, with accelerometers located in such a way that leg movements may be related to body movements, and each subject movement may be related to the movement of the aircraft. To correlate limb position and limb acceleration data, some method should be devised to synchronize the inputs from all accelerometers involved and the motion pictures taken. It may be possible to have the movies of the subject and the instrumentation from the accelerometers on the same film. In a second possible measurement system the method of interrupted lights, as described by the University of California, (ref. 9) might be used. From these data, specific movements, accelerations, forces, and major movement patterns could be analyzed.

Discussions with personnel at the University of California Medical Center, San Francisco, California, have led the experimenters to think it would be valuable to devise some means of partially simulating, by means of a laboratory suspension device, the parameters involved in zero-G walking. Preliminary biomechanical hypotheses could then be drawn concerning zero-G walking behavior, and specific force patterns could be isolated to be studied further through the use of the zero-G aircraft. The relationships between normal, partial and zero-G walking behavior could be methodically studied aboard the aircraft.

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